Title
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Introduction:

Dental analyses remain one of the most prominent and informative avenues of research within bioarchaeological practice and biological anthropology more broadly (Scott et al. 2018; Smith 2018; Hilson 1996). Teeth are well persevered in the archaeological and paleontological record as a result of enamel – the hardest substance in the human body comprised almost entirely (95%) of the inorganic non-vascular enameloid hydroxyapatite (Hilson 1996). From an anthropological perspective, teeth provide an invaluable source of information of past peoples and hominin ancestors due to their taphonomic resiliency, shedding light on dietary behaviors (Lovejoy 1985; El-Zaatari 2010; El-Zaatari 2008; Powell 1985; Scott et al. 2005; Smith 1984), stress during growth and development (Bailit et al. 1970; Barrett, Guatelli-Steinberg, and Sciulli 2012; King, Humphrey, and Hillson 2005; Goodman and Rose 1990; Temple, Nakatsukasa, and McGroarty 2012; Guatelli-Steinberg 2008; Guatelli-Steinberg, Larsen, and Hutchinson 2004; Guatelli-Steinberg, Sciulli, and Edgar 2006), biological kinship (Stojanowski 2003; Stojanowski 2004; Klaus 2013; Pilloud and Larsen 2011; Pilloud et al. 2016; Pilloud and Kenyhercz 2016), and evolutionary forces.

Yet despite its hardness, enamel is still susceptible to microfractures, chipping, and grooving as a result of both sustained and traumatic activities. A wide range of both dietary and non-alimentary activities can thus drastically alter the morphology and distribution of enamel on a given tooth beyond its original morphology. We focus here on three distinct activity-induced dental modifications (AIDMs): enamel chipping, notching, and interproximal grooving. Enamel chipping refers to irregular cracks which have removed enamel or enamel and dentine from the buccal, lingual, or interproximal edges of teeth antemortem (Bonfiglioli et al. 2004:449). This differs from enamel notching, where a depression or indentation formed on the incisal/occlusal edge is broader than it is deep, the direction often runs in a labio-lingually oriented either perpendicular or transverse to the mesial/distal axis of the tooth, and the enamel/dentine is smooth in appearance. Enamel chipping can be caused by both alimentary and non-alimentary activities (Turner and Cadien 1969; Molnar 1972; Milner and Larsen 1991; Bonfiglioli et al. 2004; Belcastro et al. 2007). Gritty dietary inclusions as well as para-masticatory processing of hard foods such as shells or bones can both lead to alimentary-based enamel chipping. Non- alimentary chipping is often distinguishable from alimentary-based chipping by its location, typically situated on anterior teeth and on both chewing and interproximal surfaces. Such chips are often caused by trauma induced by non-dietary forces such as using the teeth as a vice. Notches however are formed as a product of repeated placement of foreign objects within the mouth (Schour and Sarnat 1942; Cruwys, Robb, and Smith 1992; Bonfiglioli et al. 2004). In particular, the presence of V-shaped dental crowns and incisor notches is likely caused by holding bucco-lingually oriented objects between occluding incisal surfaces, such as needles, pins, or nails (Capasso 1999; Lorkiewicz 2011; Bonfiglioli et al. 2004).

Finally, interproximal grooving has a long history of study in bioarchaeology and paleoanthropology (Siffre 1911; Ubelaker, Phenice, and Bass 1969; Wallace 1974; Schulz 1977; Berryman, Owsley, and Henderson 1979; Larsen 1985; Bermudez de Castro and Pérez 1986; Frayer and Russell 1987; Formicola 1988; Formicola 1988; Eckhardt 1990; Brown and Molnar 1990; Frayer 1991; Bermudez de Castro, Arsuaga, and Pérez 1997; Ungar et al. 2001; Bonfiglioli et al. 2004; Sun et al. 2014). First identified by Siffre (1911), interproximal grooves are tubular, semi-cylindrically shaped depressions that are located interproximal locations of the cervical surfaces, typically at or below the cemento-enamel junction (CEJ). The presence of these grooves has been observed in early hominin species, at least as old as Homo habilis 1.8 million years ago (Ungar et al. 2001). Yet, the etiological explanation for how these grooves form has received considerable debate. Siffre (1911) first suggested that given the tubular appearance and bucco-lingual orientation along the CEJ, these grooves were likely the product of incessant tooth-picking. Wallace (1974) disagreed, arguing that the grooves were rather the result of dietary grit and inclusions suspended in saliva that facilitated localized irritation and abrasion, possibly through a sucking motion. He suggested that the force of sucking saliva or even swallowing could possibly pull gritty inclusions through interproximal spaces and thus abrade cervical surfaces. Brown and Molnar (1990) also posited a different etiology, using ethnographic videos and interviews with indigenous communities in Australia to suggest these grooves were the product of sinew and fiber processing. However, fiber and sinew processing typically is limited to anterior teeth (Larsen 1985; Schulz 1977), and the presence of localized grooves only present on interproximal surfaces of posterior teeth paired with the vast geographic and temporal distribution of these observed grooves likely challenge the idea that these are produced by sinew processing alone (Frayer 1991). Rather, the vast majority of literature supports the notion that these grooves are in fact produced by incessant tooth-picking, by introducing an exogenous material such as a twig for palliative and hygienic purposes (Siffre 1911; Formicola 1988; Ungar et al. 2001; Ubelaker, Phenice, and Bass 1969; Berryman, Owsley, and Henderson 1979; Schulz 1977; Frayer and Russell 1987; Frayer 1991; Bermudez de Castro, Arsuaga, and Pérez 1997; Alt and Pichler 1998; Lorkiewicz 2011; Alt and Koçkapan 1993). While Formicola (1988) suggests that this behavior can become psychologically reinforced as a habit, the practice of tooth-picking for psychological or therapeutic, palliative, and hygienic purposes seems the most supported interpretation for the presence of these grooves. While some have found no evidence of carious lesions associated with these grooves (Berryman, Owsley, and Henderson 1979), the presence of carious lesions or periodontitis with these grooves provide further support for the hygienic and therapeutic role of tooth-picking in their formation.

We present here preliminary analyses on two individuals that showed macroscopic evidence of interproximal grooving, enamel chipping, and enamel notching. We conduct microscopic analyses using Scanning Electron Microscopy (SEM) to help differentially diagnose the etiological origin of the 'lesions' observed macroscopically. In doing so, we test whether these defects are associated with palliative oral hygiene, craft production in using teeth-as-tools, and/or dietary mastication.

Materials:

The dentition analyzed here belong to two individuals from the Late Medieval (c. 1350 – 1500) site of Villamagna, Italy. Located 75 km southeast of Rome (Figure 1), Villamagna was originally established as an imperial estate under the Roman Empire and frequented by young emperor Marcus Aurelius, before converting into a monastery and peasant village from the late tenth to the late thirteenth century (Fentress and Maiuro 2011). It was later converted into a castrum, or fortified village until the early fifteenth century (Fentress, Goodson, and Maiuro 2016). Archaeological excavations of the site revealed a relatively large (n = 404 individuals) cemetery in proximity to the medieval monastery and S. Pietro church (Goodson 2016). Given the varying demographics of the site, it is thought that the cemetery represents a sample of the rural vassal population who had labor ties to the estate, and not necessarily a monastic cemetery proper, which would more likely be characterized by exclusively male burials (Fentress, Goodson, and Maiuro 2016).

Two individuals, HRU 2828 and HRU 4142 were analyzed closely for varying activity induced dental modifications (AIDMs) observed macroscopically during procedural dental analyses (Trombley et al. 2019).

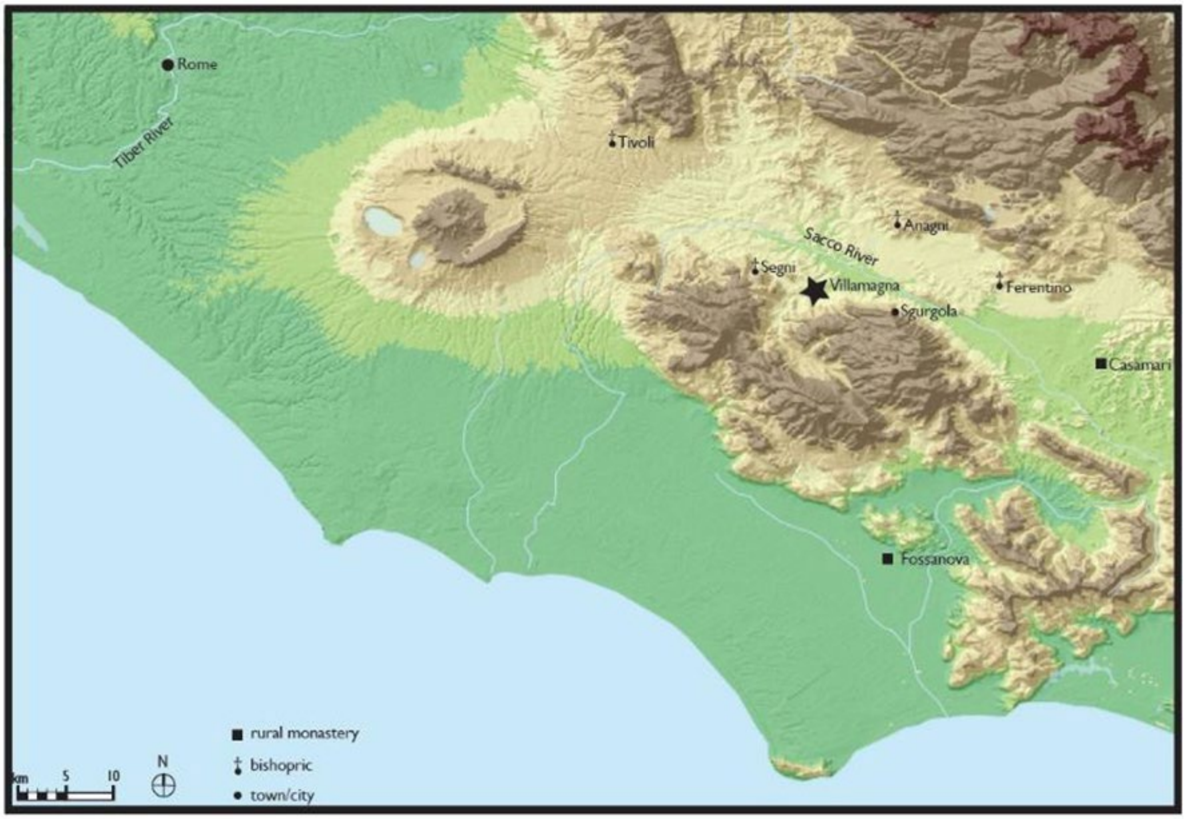

Figure 1. Location of Villamagna within the Sacco valley of Lazio

Methodology:

Demography

Age-at-death was assessed in these two individuals according to multiple indicators of degenerative changes in the pubic symphysis (Brooks and Suchey 1990) and auricular surface (Lovejoy et al. 1985). Given the large amount of pathology and physical activity at Villamagna (forthcoming), we employed three broad, conservative age groups (18-29 years, 30-49 years, 50+ years). Sex was estimated by analyzing distinguishing features in the pubic symphysis (Brooks and Suchey 1990; Brothwell 1981; Buikstra and Ubelaker 1994), as well as the cranium when necessary (Mays, Lees, and Stevenson 1998).

HRU 4142 displayed classic female Phenice traits, with prominent ventral arc, sub-pubic concavity and constriction, and a wide sub-pubic angle. The pubic symphysis and auricular surface scores were 5 and 7 respectively, suggesting an older-age (50+ years) individual. HRU 2828 displayed classic male pelvic morphology, lacking any of the Phenice traits. Mandibular ramus and excessive gonial flaring also strongly suggest male. The pubic symphysis and auricular surface scores were 3-4 and 4-5 respectively, firmly suggesting a middle aged (30-49 years) individual.

Dental inventory

All traits relating to dental inventory were visually examined with the naked eye, aided by diffuse lighting. Tooth presence was scored according to Buikstra and Ubelaker (1994). Teeth lost antemortem were identified on the basis of alveolar resorption and remodeling of the alveolar sockets. This helps to differentiate antemortem tooth-loss from post-mortem, as post- mortem tooth loss is characterized by the presence of alveolar sockets with no associated teeth and no signs of alveolar remodeling or resorption. Dental caries – a multifactorial infectious disease whereby the enamel surface of teeth become demineralized as a result of acidogenic bacteria – were identified based on the presence of demineralized enamel surfaces, ranging from a localized pin-prick to complete destruction of the crown surface. The location of each carious lesion on the tooth surface was also recorded following Buikstra and Ubelaker (1994:55). Periapical lesions were recorded on a presence/absence basis, only if there was a clear presence of a drainage channel accompanied by a necrotic cavity and resorptive activity (Dias and Tayles 1997). Dental calculus was scored based on the three-stage ordinal scale by Brothwell (1981), while also noting its location on the tooth surface. In cases where calculus covered multiple surfaces, the location was scored as 'multiple.' Periodontal disease, or periodontitis, was scored based on the ordinal system developed by Kerr (Kerr 1988; Kerr 1991). While periodontitis in skeletal remains is often identified by the presence of alveolar resorption and recession of the alveolar crest by employing metric thresholds (e.g. greater than 2mm distance between the CEJ and alveolar crest; see DeWitte and Bekvalac 2010), the Kerr method helps to account for continued eruption of teeth throughout life (Varrela et al. 1995; Whittaker and Molleson 1996; Clarke and Hirsche 1991; Hildebolt and Molnar 1991; Craddock and Youngson 2004; Costa 1982) by scoring each inter-dental septa separately.

Activity-induced dental modifications (AIDMs)

To score enamel chipping, we used the three-grade system developed by Bonfiglioli and colleagues (2004): Grade 1) slight crack or fracture (0.5m) or larger but superficial enamel flake loss; Grade 2) square irregular lesion (1mm) with the enamel more deeply involved; Grade 3) crack bigger than 1mm involving enamel and dentine or a large, very irregular fracture that could destroy the tooth. Similar to enamel chipping, enamel notching was scored on a three-grade system (Bonfiglioli et al. 2004): Grade 1) slight superficial indentation affecting only the enamel; Grade 2) Wider and deeper indentation with polished dentine; Grade 3) very deep and equally wide depression with heavily polished dentine. To further investigate notches and grooves in these individuals, Scanning Electron Microscopy (SEM) was employed. Teeth were analyzed using a Hitachi TM-1000 housed at the University of California, Berkeley Archaeological Research Facility Imaging Laboratory, at varying levels of magnification to identify micro-striae and surface texture of the enamel lesions.

Results:

Dental pathological lesions

Both HRU 2828 and HRU 4142 were relatively well-preserved, with 32 and 29 loci being observable, respectively. However, both individuals displayed significant amounts of dental pathological lesions (Table 1). HRU 2828 showcased significant antemortem tooth loss (62.5%), only retaining 11 total teeth by the time of death (Figure 4). At least 4 of the teeth lost antemortem were likely due to periapical inflammation, likely abscesses, evidence by the lingual drainage channels at the location of their respective loci (Figures 2-3). At least 6 of the 11 teeth (54.5%) displayed signs of cavitation, and 5 (45.5%) contained calculus accretions. Individual 2828 also shows excessive alveolar recession, far greater than 2mm in many cases, but several of the septa (n = 4) show only minor changes in architecture. Due to the heavy AMTL, this individual likely had continued eruption throughout life for the remaining

11 teeth, rather than extreme periodontal disease. The maxillary left first molar (LUM1) helps to support this, with roots extending even beyond/over the alveolar margin, with a portion of the upper mesio-buccal root actually narrowing, likely to provide an anchor. However, at least 60% of 2828's observable interdental septa (n = 6) displayed evidence of acute, quiescent, or aggressive periodontitis (scores greater than 3; see Kerr 1998, 1991 for further details). Only the interdental septa between the maxillary left secondary premolar (LUP2) and first molar (LUM1) showed evidence of aggressive periodontitis (score of 5) with a steep-sloping intra-dental defect accompanied by smooth, honeycombed texture.

HRU 4142 displayed much lower rates of AMTL (20.7%), and carious lesions (31.8%), but higher rates of calculus accretions (68.2%; Table 1; Figures 5-8). The mandibular left lateral incisor (LLI2) showcases extreme calculus (score of 4), covering almost the entire circumference of the cervical portion of the tooth, and forming a "tent" like shelf of calculus projecting from the crown mesially towards the midline (Figure 6). Individual 4142 showcased signs of excessive periodontitis (78.6%), all of which were scores of 5, suggesting aggressive and rampant periodontitis throughout the entirety of the oral cavity. Finally, the left mandibular ramus showcases signs of TMJ, given the lipping, porosity, and degradation of the joint surface (Figure 8).

HRU	*N obs. loci*	*Obs. teeth N (%)*	*AMTL N (%)*	*Carious N (%)*	*Calculus N (%)*	*N obs. Septa*	*Periodontal N (%)*	*Abscess N (%)*
2828	32	11	20 (62.5)	6 (54.5)	5 (45.5)	10	6 (60)	4 (12.5)
4142	29	22	6 (20.7)	7 (31.8)	15 (68.2)	14	11 (78.6)	3 (10.3)

Table 1. Dental Pathological lesions in HRU 2828 and HRU 4142

Activity Induced Dental Modifications (AIDMs)

HRU 2828 displays extramasticatory wear on the labial portion of the mandibular incisors, with excessively steep wear running labio-lingually (Figures 3-4). The maxillary left second premolar (LUP2) displays a prominent, semi-circular interproximal groove running bucco-lingually along the mesial surface of the root, just superior to the CEJ (Figure 9a). There appears to be a similar groove on the distal portion of the tooth, but is likely more incipient (Figure 9b). SEM images show micro-striae present within the interproximal groove, oriented bucco-lingually and parallel to the groove (Figure 10c-d). Individual 2828 shows no signs of enamel chipping or notching.

HRU 4142 displays various types of AIDMs. At least 8 maxillary teeth exhibit enamel chipping (36.4%), while no mandibular teeth showed evidence of enamel chipping: RUM1, RUP2, RUP1, RUI1, LUI1, LUI2, LUC, and LUP1. At least 4 teeth (18.2%) also showed evidence of dental notching: the maxillary left central incisor (LUI1, score = 3), the maxillary left canine (LUC, score = 2), the mandibular right first molar (LRM1, score = 3) and the mandibular left lateral incisor (LLI2, score = 1). The maxillary right central incisor (RUI1) and maxillary left lateral incisor (LUI2) may also contain notches, but given the severity of enamel chipping, it is difficult to discern. The maxillary right central incisor (RUI1) contains V-shaped wear that runs labio-lingually, with almost the entirety of enamel chipped or worn off (Figure 11). The maxillary left central incisor (LUI1) however, showcases V-shaped wear that runs mesio-distally, with the apex located at aforementioned notch and chip (Figure 12). The tooth also exhibits lingual surface attrition of the maxillary anterior teeth (LSAMAT), with steep enamel polishing on the lingual aspect of the crown surface (Figure 12b). SEM images show that the labial enamel chip contains a rough and rugged surface, with the mesial-most border of the enamel chip coinciding with the enamel notch (Figure 12c). The interproximal enamel chip similarly showcases rough and rugged topography (12d).

Figure 2. HRU 2828 maxilla, anterior view

HRU 2828's maxilla shows signs of excessive periapical inflammation on the labial/anterior alveoli for both medial incisors and the left lateral incisor.

Figure 3. HRU 2828 mandible, anterior view

HRU 2828's mandible shows signs of periodontitis given the excessive alveolar resorption and jagged architecture. Evidence of periapical inflammation on the labial/anterior portion of the left mesial mandibular incisor. Note the excessive labial/vestibular wear on the incisors.

Figure 4. HRU 2828 mandible, view of right mental foramen

Signs of excessive AMTL, given the overall smooth texture of the posterior alveoli and recession of alveolar margin. This likely suggests the posterior dentition in the mandible were lost quite some time before death, given the completely remodeled and smooth appearance. Evidence of cavitation on the mandibular left first premolar (LLP1)

Figure 5. HRU 4142 maxilla, anterior view

Figure 6. HRU 4142 mandible, anterior view

Figure 7. HRU 4142 large periapical inflammation of the maxillary second and third right molars

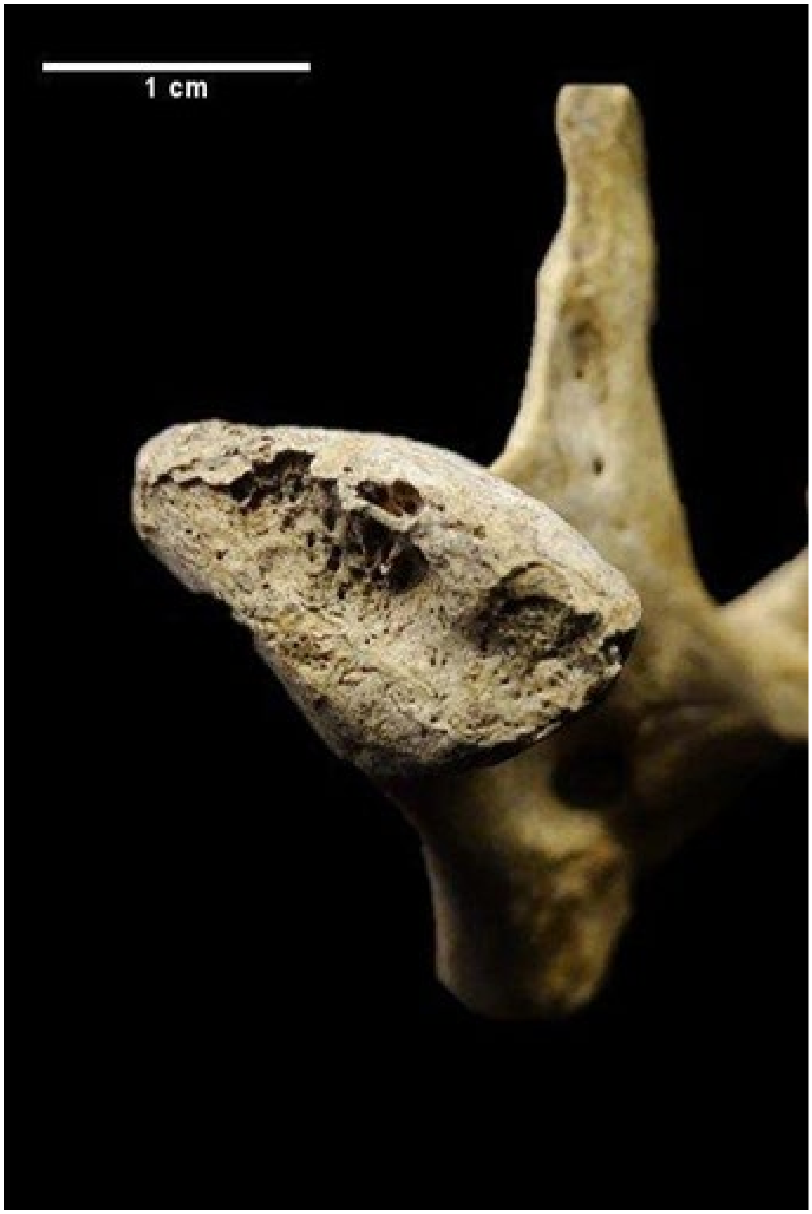

Figure 8. HRU 4142 left mandibular ramus showcasing evidence of TMJ

Figure 9. HRU 2828 maxillary left second premolar (LUP^2)

2828 left maxillary second premolar (LUP2) with evidence of interproximal grooving. A) mesial view; B) distal view; C) lingual view; D) buccal view. Note the cavitation present within the interproximal mesial and distal grooves, as well as "hourglass" shape of the root superior to the CEJ.

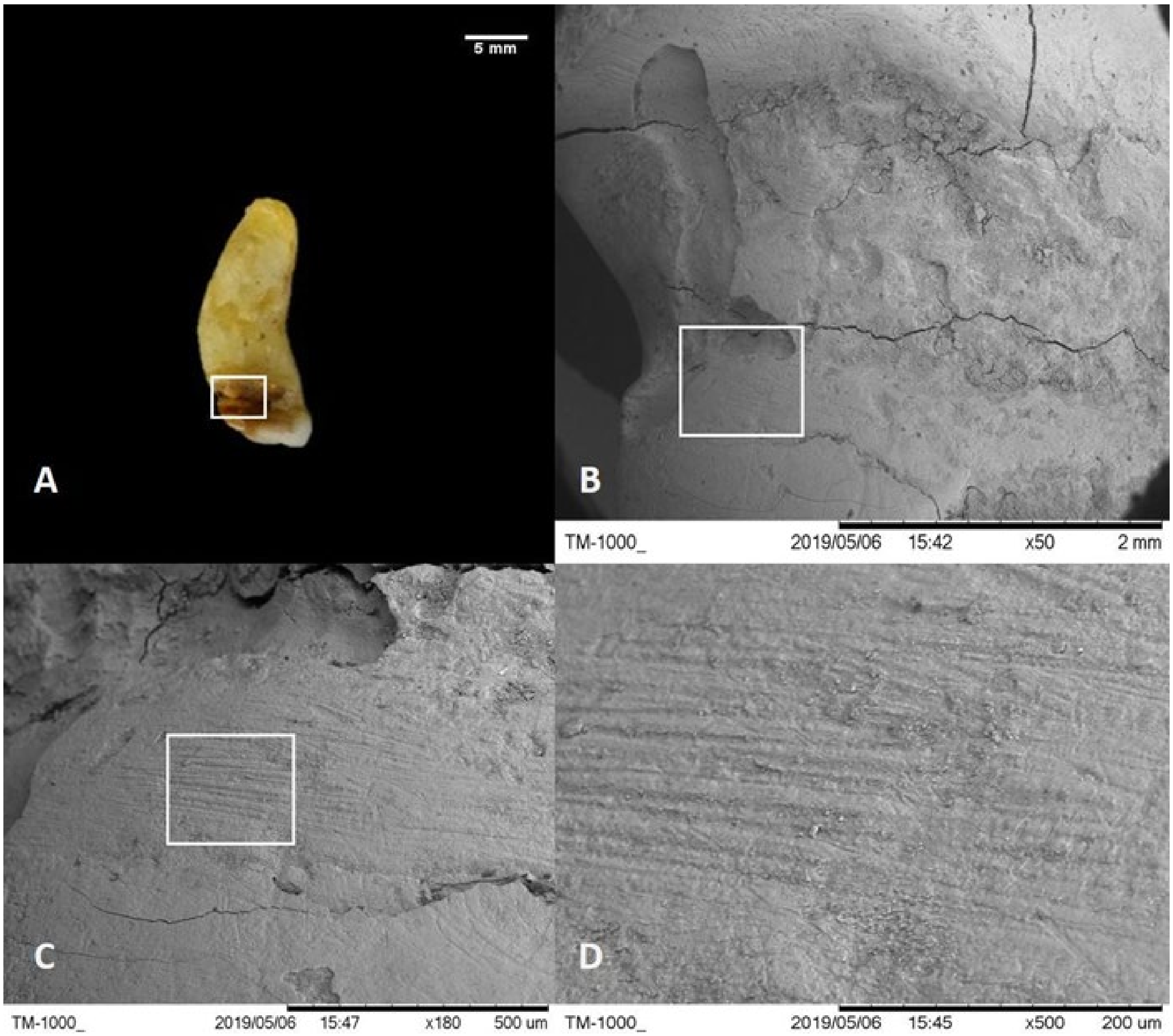

Figure 10. HRU 2828 maxillary left second premolar (LUP^2)

A) mesial macroscopic view; B) SEM image (50x) of mesio-lingual portion of the groove, outlined by white square in A; C) SEM image (180x) of microstriae, outlined by white square in B; D) SEM image (500x) of microstriae, outlined by white square in

C. Note the orientation of microstriae are in line with the groove, running bucco- lingually and parallel to the CEJ.

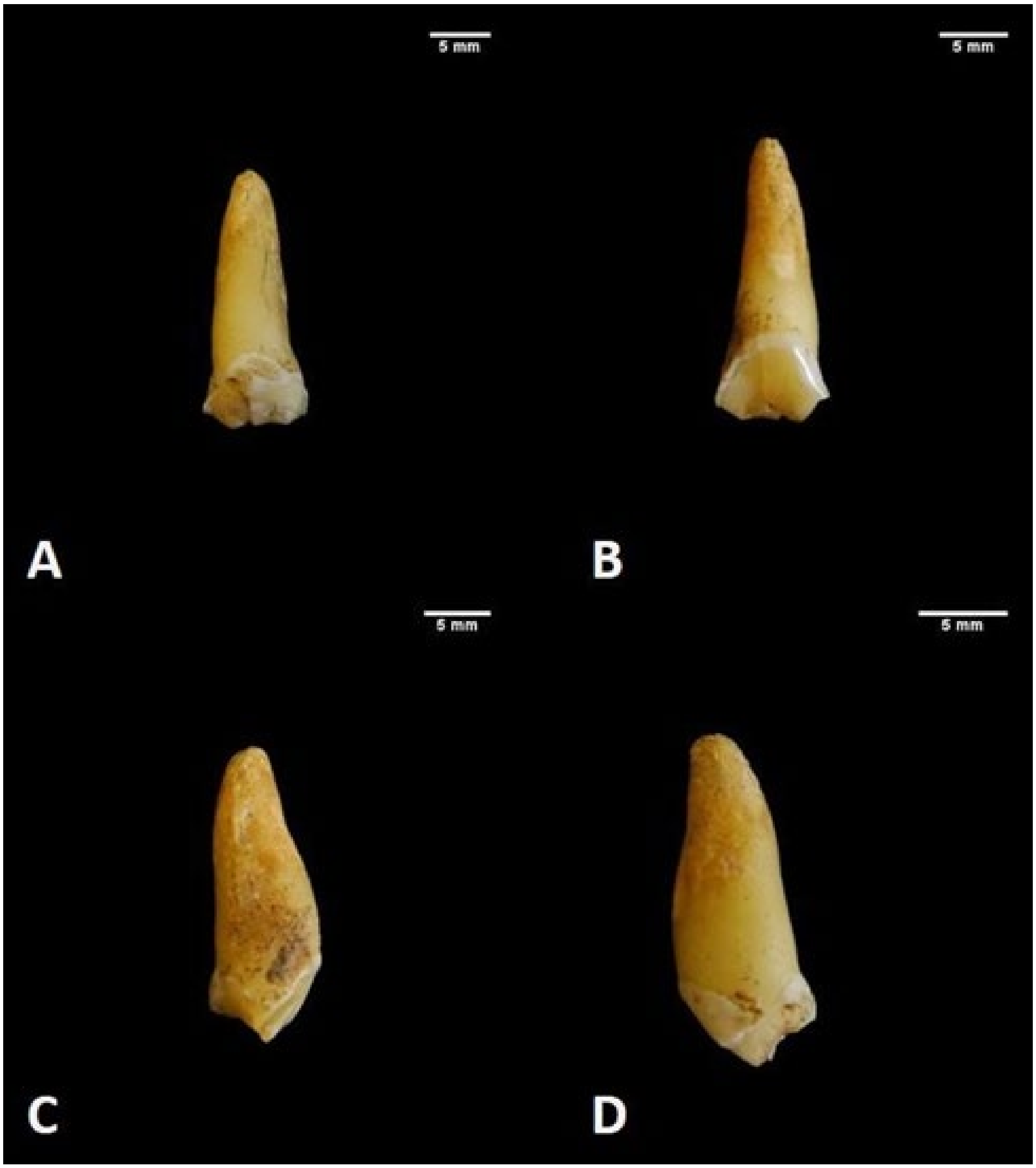

Figure 11. HRU 4142 right maxillary central incisor (RUI^1)

2828's right maxillary central incisor (RUI^1) with evidence of AIDM. A) labial/vestibular view; B) lingual view; C) mesial view; D) distal view. Note the V-shape of the crown from the interproximal views, with a rough/jagged labial surface and smooth lingual surface.

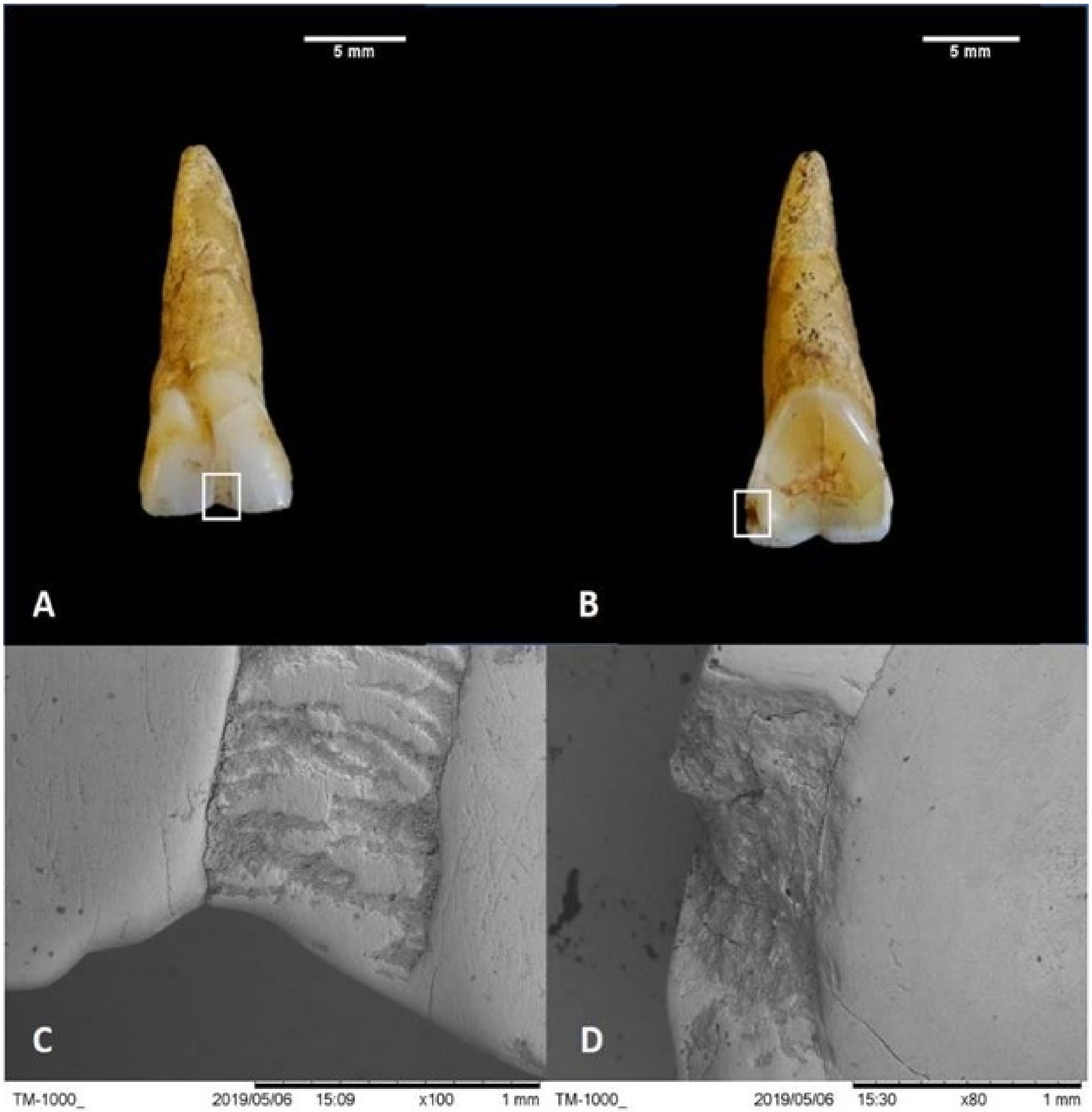

Figure 12. HRU 4142 left maxillary central incisor (LUI^1)

4142's left maxillary central incisor (LUI^1) with evidence of both notching and enamel chipping. A) labial macroscopic view; B) Lingual macroscopic view; C) SEM image (100x) of incisal notch and enamel chip, outlined by white square in A; D) SEM image (80x) of distal enamel chip, outlined by white square in B.

Discussion:

Both HRU 2828 and HRU 4142 display sufficient amounts of dental pathological lesions. The high rates of AMTL, carious lesions, periodontitis, and periapical inflammation are not surprising, given previous research conducted on the dental remains at the site (Trombley et al. 2019). However, enamel chipping, notching, and grooving are worth considering further. HRU 2828 showcases little evidence of AIDMs other than interproximal grooving on the maxillary left second premolar (LUP2). Given that the groove 1) runs bucco-lingually along the interproximal cervical surface, 2) contains micro-striae oriented in a parallel, bucco-lingual fashion in accordance with the groove, and 3) is tubular in shape, tapering towards the buccal and lingual aspects, this groove is most likely the result of an exogenous implement abrading with the root surface for hygienic or palliative reasons (Siffre 1911; Formicola 1988; Ungar et al. 2001; Ubelaker, Phenice, and Bass 1969; Berryman, Owsley, and Henderson 1979; Schulz 1977; Frayer and Russell 1987; Frayer 1991; Bermudez de Castro, Arsuaga, and Pérez 1997; Alt and Pichler 1998; Lorkiewicz 2011; Alt and Koçkapan 1993). Notably, both the prominent mesial groove and incipient distal groove show signs of sub-cervical cavitation throughout the groove. Additionally, the interdental septa between the maxillary left second premolar and first molar showed signs of aggressive periodontitis, given the steep topography and honey-comb texture. Taken together, the individual contained both cavitation and advanced periodontitis surrounding this tooth, bolstering the idea that such grooves were likely produced as a result of palliative abrasion in order to relieve pain.

The overall oral cavity for HRU 2828 is also worth considering further, as they retained maxillary teeth only in the mandible with no mandibular posterior dentition, and only posterior dentition in the maxilla (Figures 2-4). Interestingly, this suggest that there were no occluding teeth available for the individual, rather the individual would have had to occlude material either between mandibular anterior teeth and maxillary gums, or maxillary posterior teeth and mandibular gums. The extramasticatory wear on the mandibular incisors may be dietary but could possibly result from non-alimentary activities as well. While the maxillary teeth are absent, the steep wear resembles LSMAT, which is typically seen on the maxillary teeth and not mandibular. The wear on the mandibular teeth may have been worn as a result of non-dietary contact with an exogenous material, given the AMTL, heavy resorption, and periapical inflammation of the occluding maxillary incisors. In this sense, the upper teeth may have been preferentially used until they were lost, resulting in a substitution of the mandibular teeth for similar activities.

HRU 4142 displayed no interproximal grooves but did display significant amounts of enamel chipping and notching. Enamel chips located on the posterior dentition are likely the result of gritty dietary inclusions, given the large portion of enamel removed paired with their occlusal-apical orientation. Previous research suggests that diets were likely gritty, given heavy dental wear (Trombley et al. 2019). This could be from gritty inclusions within foodstuffs, or possibly as a result of marl – medieval fertilizer consisting of a mixture of clays, calcium, and lime carbonates (Jones 2004; Mathew 1993), though it is likely that such inclusions were removed in the preparation of foodstuffs. Chipping present on anterior dentition however is likely the result of non-alimentary activity, due to the smaller size of enamel removed, as well as the location along the labial/incisal surfaces – areas not typically used in mastication. The maxillary left central incisor enamel chip along the midline coincides with the apex of the enamel notch (Figure 12). This suggests the chip was likely a product of exogenous, non- alimentary material being repeatedly held between the teeth.

We suggest that both the chip and groove are likely the product of the placement of a sewing needle within the mouth. Analyzing various groups from Neolithic to late Medieval England, Cruwys and colleagues (1992) identified notches on incisors and canines likely attributable to the processing of soft materials such as wood or sinew, as well as threading/stringing bows which often employ the aid of teeth. Sperdutti and colleagues (2018) identified notches in teeth as evidence of fiber production and manipulation, likely hemp, from the Italian eneolithic/bronze age cemetery of Gricignano d'Aversa, Italy. Their interpretations were further supported by further microscopic analyses of dental calculus, which showcased evidence of hemp fibers present within dental calculus associated with notched teeth. Future research evaluate whether dental calculus contains fibers from the remains at Villamagna. Archival evidence from the central medieval period suggests that many of the properties had cannapinae hemp groves (Goodson 2016:284–286). Archaeological remains of n = 18 spindle whorls, n = 4 spindle hooks, n = 18 needles, and n = 1 loom weight were also found at the site, suggesting textile craft production was certainly practiced (Figure 13). The maximum width of the diameter from the maxillary left central incisor falls within the distribution of needle diameter dimensions, suggesting the repeated placement of a needle in the mouth could have likely produced the notched and chip (Figure 14). Altogether, this likely suggests that enamel chipping and notching on the anterior labial surfaces are likely the product of craft-related activities, such as fiber processing, sewing, and textile production.

Figure 13. Spindle hook (A), Needle (B) and Spindle Whorl (C) from Villamagna

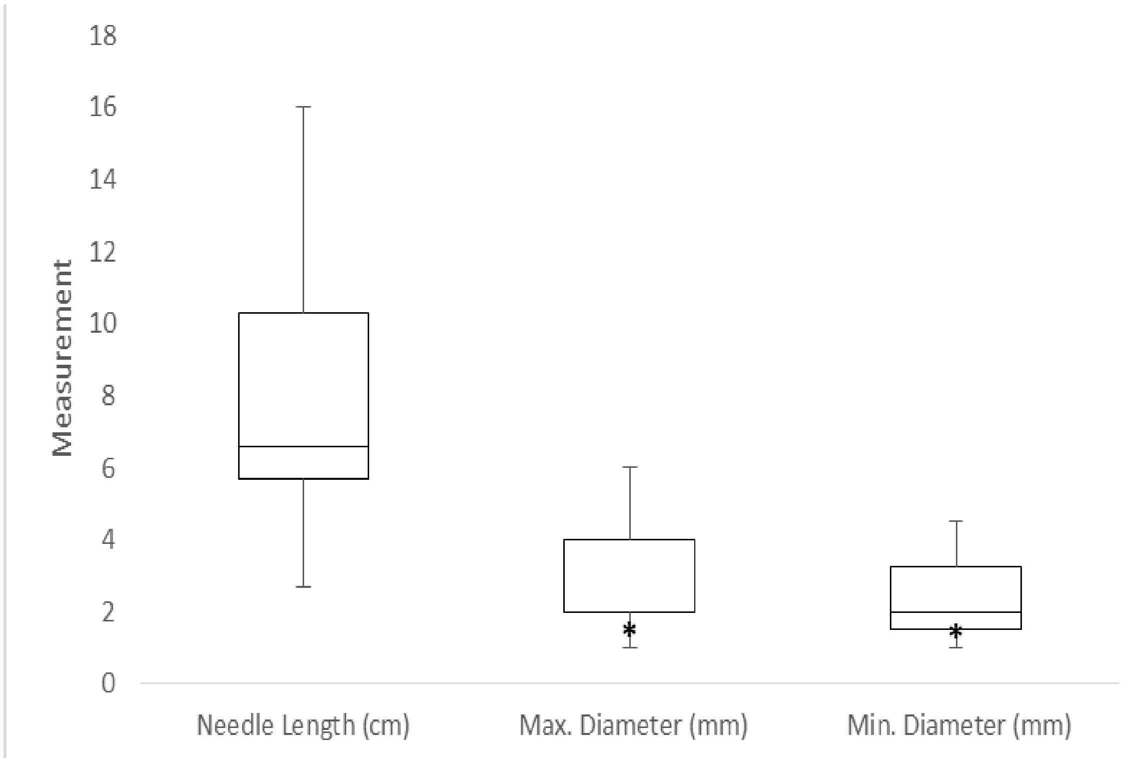

Figure 14. Distribution of needle dimensions at Villamagna

** refers to the notch width of the maxillary left central incisor from HRU 4142. Note how the width falls within the quartile group 1 in the maximum diameter, and lower quartile on the minimum diameter.*

Conclusion:

While there is a long history of bioarchaeological research on dental modifications, enamel chipping and notching have not received as much attention. Yet, analyses of enamel chipping, grooving, and notching can reveal important insights into diet, craft production, and oral hygiene. While this research is preliminary, the bioarchaeological data presented here, alongside archival and archaeological materials, suggests that both palliative, oral hygienic regimens and craft production, likely sewing and textile manufacturing, were practiced within the late medieval community of Villamagna. Future research will need to analyze chipping, grooving, and notching more systematically to see how craft production and oral hygienic regimens may pattern across demographic groups. Additionally, research on dental calculus may provide further insight into craft production with the inclusion of craft material such as fibers.

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